Exterior Structural Composite Panels With Southern Pine Veneer Faces and Cores of Southern Hardwood Flakes

Chung-Yun Hse

Abstract

One-half-inch-thick, structural exterior composite panels of various constructions were made in a one-step process, with faces of southern pine veneer and cores of mixed southern hardwood flakes. The flakes were precisely machined to be 3/8-inch wide, 3 inches long, and 0.015 inch thick. Two veneers, cross-laminated on each face over an oriented flake core, yielded the strongest panels. Panels with single veneer faces and random cores were most stable parallel to the grain of face plies. Average MOR of 9,153 psi and MOE of 1,731,000 psi for panels with single-veneer faces and random cores are considered more than adequate for most applications, even though these values are slightly lower than those of panels with two veneers on each face. Within the range of the experiment, the combinations of 1/16-inch, single-ply faces with a random core provided adequate strength and good dimensional stability. The simplicity of single-ply faces and the ease of forming random-flake cores made such construction the best candidate for a one-step hot press operation in existing panel plants. The panels had an average MOR of 10,400 psi and MOE of 1,696,000 psi. In vacuum-pressure-soak cycles the panels had water absorption of 101 percent and thickness swell of 24.2 percent; linear expansion parallel and perpendicular to the grain of face plies averaged 0.142 and 0.617 percent. Whole-panel density (at 5% MC) was about 41.8 pcf.

Building panels for structural roof sheathing and subfloors must be both stiff and strong. Sheathing grades of plywood possess the requisite stiffness and strength, but supplies of veneer are limited, and demand for sheathing is expected to rise during the latter part of this century. To relieve the anticipated shortage of softwood veneer, it has been proposed that flakes or particles be substituted for inner plies of veneer. Interest in the proposal has been quickened through much recent research by industrial and university laboratories, government agencies, and trade associations. (see, e.g., 1-4).

Such research at the Pineville, Louisiana, laboratory of the Southern Forest Experiment Station has been concentrated on making composite panels with faces of southern pine veneer and cores of mixed southern hardwood flakes. Two major steps toward industrial practicability were accomplished with formulation of an economical fast-cure phenolic binder for both hardwood flakes and pine veneer[1], and laboratory demonstration that the panels could be hot-pressed in a one-step operation[2]. It has yet to be shown, however, that the one-step technique practical for 20- by 20-inch panels will work on 4- by 8-foot panels. Moreover, information is fragmentary on effects of core design and face veneer thickness.

In an effort to elucidate the second of these information voids, 72 small composite panels of differing constructions were fabricated and tested for physical and mechanical properties.

Procedure

Design of Experiment

Factors in the study were:

- Number of face veneers
  - Single veneer on each face
  - Two veneers, cross-laminated, on each face
- Veneer thickness
  - 1/10-inch
  - 1/16-inch
  - 1/24-inch
- Arrangment of core flakes
  - Homogeneous, random orientation
  - Homogeneous, oriented in direction perpendicular to the grain of veneers in immediate contact
  - 3-layer, cross-oriented
- Replications of panels: 4

[1]Hse, C.-Y. 1975. Formulation of economical fast-cure phenolic resin as binder for exterior hardwood flakeboard. Final Report FS-SO-3201-2.54, Southern Forest Expt. Sta., USDA Forest Serv.

[2]Hse, C.-Y. 1972. Hardwood-flake-core-and-pine-veneer-face panel for exterior use. Paper presented at Southeastern Section meeting of Forest Products Research Society, Pensacola, Fla., October.

The author is Principal Wood Scientist, Southern Forest Expt. Sta., USDA Forest Service, Pineville, La. This paper was received for publication in August 1975.

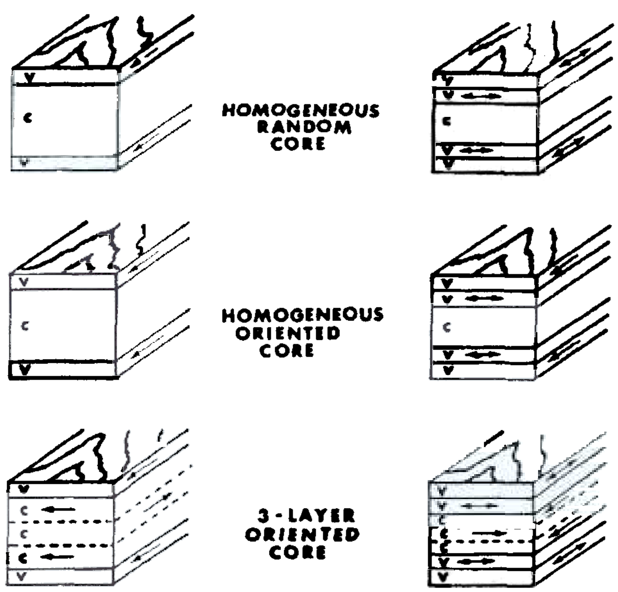

Figure 1. — Arrangements of face veneers (V) and core flakes (C). Arrows indicate grain direction. Left, single veneer on each face. Right, two veneers cross-laminated on each face.

Thus the panels were variously constructed with two or four veneers and one core layer (which might be random or oriented), or three oriented core layers (Fig. 1).

Board Manufacture

Veneer preparation. — Six loblolly pines, approximately 12 inches in diameter at breast height (DBH), were cut in central Louisiana. To obtain end-matched veneer specimens, each tree was sawed into six 40-inch bolts. The bolts were randomly divided into three groups for peeling into the three veneer thicknesses; i.e., two bolts per tree for each thickness.

All bolts were submerged in hot water (180°F) for 24 hours prior to peeling. The veneers were produced with a 4-foot lathe at a plywood mill in central Louisiana. All veneers were sawed into 19- by 20-inch specimens and dried in a kiln to an average moisture content (MC) of 4 percent. To control variability, clear veneer only was used in the experiment.

Preparation of flakes. — Flakes were prepared from red oak, hickory, and sweetgum with a laboratory peeling machine coupled to a rotating flake clipper. Flakes measured 3 inches long, 3/8 inch wide, and 0.015 inch thick. All were dried to an average MC of 3 percent.

Resin application. — Resin was sprayed on veneers to achieve 5 pounds of resin solids per 1,000 square feet of single glueline. Core flakes were weighed to yield a core density of about 43.7 (basis of ovendry (OD) weight and volume at 5% MC) and placed in a rotating drum-type blender. Phenolic resin in amounts equal to 3 percent of the OD weight of flakes was applied by air-atomizing nozzle. The resin, prepared in the laboratory, was formulated as 46 percent solids with molar ratio of formaldehyde to phenol of 1.85. Formulations applied to face veneers and core flakes were identical.

Panel preparation. — All panels (size 19 by 20 inches with thickness of 1/2 inch) were prepared in the laboratory. The flakes, after blending, were carefully felted on a face veneer in the forming box. All cores were prepared as a mixture of 50 percent red oak, 25 percent hickory, and 25 percent sweetgum. The core mat with face-veneer on both sides was transferred immediately to a 20- by 20-inch single-opening hot press at 335°F. Sufficient pressure (about 400 psi) was applied so that the platens closed to 1/2-inch stops in approximately 45 seconds. Closed press time was 5 minutes.

Sampling and Testing

All boards were conditioned in a chamber controlled at 50 percent relative humidity (RH) and 80°F before testing; ending MC averaged 4.8 percent. After conditioning, each board was cut to yield two static-bending specimens and four dimensional-stability specimens (two each for vacuum-pressure-soak and 5-hour-boil tests).

Mechanical tests were performed in accordance with ASTM standards for evaluating the properties of wood-base fiber and particle panel materials (D 1037-64). The MOR and MOE were calculated with the assumption that the cross section of the composite panel was homogeneous.

The vacuum-pressure soak test (VPS) consisted of soaking 3- by 9-inch specimens in water vacuum (30-in. Hg) for 30 minutes and then under 65 psi pressure (at room temperature) for 24 hours. Weights, thicknesses, and lengths were measured before and after soaking.

For the boil test, 3- by 9-inch specimens were soaked in boiling water for 5 hours. Weights, thicknesses, and lengths were measured before and after soaking.

Results

Strength

Average physical and mechanical properties of the panels are summarized in Table 1. (It should be noted that strength perpendicular to the grain of the face panels was tested only on one-ply panels.) Effect of veneer thickness, number of face veneers, and core flake arrangement were evaluated by analysis of variance at the 0.05 level of probability, and all differences discussed were significant at that level.

Bending strength (MOR). — Average MOR in stress parallel to the grain of the face panels was least—4,500 psi—for panels with single 1/24-inch veneers on each face over an oriented core. It was greatest — 15,843 psi — for panels with two 1/16-inch veneers cross-laminated on each face over an oriented flake core.

With values for all core constructions pooled, MOR differed significantly with face veneer thickness. Averages for three veneer thicknesses and face constructions were:

Face construction and veneer thickness, inch (1)	Stressed parallel to grain of outermost face veneer (psi) (2)	Stressed perpendicular to grain of outermost face veneer (psi) (3)
Single veneer on each face		
1/10	7,842	2,521
1/16	8,110	5,030
1/24	6,214	5,501
Two veneers cross-laminated on each face		
1/10	7,743	–
1/16	13,507	–
1/24	8,674	–

As shown in column 2, MOR increased as veneer thickness increased from 1/24 to 1/16 inch, but decreased as veneer thickness increased from 1/16 to 1/10 inch. The decrease was attributed mainly to horizontal shear failures. Of all the specimens with 1/10-inch face veneers, 86 percent failed in horizontal shear; in contrast, only 27 percent of those with 1/16-inch face veneers failed in horizontal shear. These shear failures precluded accurate determinations of true MOR.

When stress was perpendicular to the grain of the outermost face veneer, MOR decreased as face veneer thickness increased (col. 3).

Interactions of core construction with face construction and number of faces affected MOR:

Face and core construction	Stressed parallel	Stressed perpendicular
	psi	
Single veneer		
Random	9,153	2,646
Oriented	5,846	5,277
Three-layer	7,167	5,122
Two veneers, cross-laminated		
Random	8,056	–
Oriented	13,161	–
Three-layer	7,207	–

MOR of panels with two veneers cross-laminated on each face over oriented cores averaged significantly higher than MOR in panels with single face veneers over oriented cores. In panels with random cores, however, MOR was slightly greater for those with single veneers on each face. Little difference was detected between one-ply and two-ply faces when the core was fabricated in three layers.

Of all panels with one-ply veneer overlays, those with random cores yielded highest MOR (i.e., 9,153 psi) when stressed parallel to the grain of the face veneer, but had the lowest MOR (2,646 psi) when stressed perpendicular to the grain; this substantially lower strength may be a disadvantage in structural applications.

Table 1. — MOR AND MOE OF PANELS WITH SOUTHERN PINE VENEER FACES AND CORES OF SOUTHERN HARDWOOD FLAKES.

Number and thickness of face plies (in.)	Flake[1]	MOR[2] Parallel	MOR[2] Perpendicular[3]	MOE[2] Parallel	MOE[2] Perpendicular[3]
		psi		10^6 psi	
One ply					
1/10	R	9,814	2,050	1.942	0.209
	O	7,125	2,680	1.685	.414
	L	6,588	2,833	1.876	.409
1/16	R	10,400	2,453	1.696	.298
	O	5,919	6,511	1.445	.791
	L	8,010	6,126	1.359	.862
1/24	R	7,245	3,456	1.434	.437
	O	4,495	6,640	1.049	1.003
	L	6,902	6,407	1.212	1.073
Two plies					
1/10	R	5,853	—	1.914	—
	O	11,359	—	1.952	—
	L	6,017	—	1.920	—
1/16	R	11,562	—	1.820	—
	O	15,843	—	1.983	—
	L	8,617	—	1.846	—
1/24	R	6,753	—	1.344	—
	O	12,281	—	1.748	—
	L	6,988	—	1.564	—

[1]R, O, and L mean random, oriented, and 3-layer flake-core respectively.
[2]In stress parallel or perpendicular to grain of outermost face veneers.
[3]Two-ply panels were not tested perpendicular to the grain of the face plies.

Stiffness (MOE). — Average MOE in stress parallel to the grain of face plies was 1,050,000 psi for panels with single 1/24-inch veneers over an oriented core, and ranged to 1,980,000 psi for those with two 1/16-inch veneers cross-laminated on each face over an oriented flake core (Table 1). MOE, like MOR, varied significantly with thickness of face veneers:

Face construction and veneer thickness, inch (1)	Stressed parallel (2)	Stressed perpendicular (3)
	---psi---	
Single veneer		
1/10	1,844,000	344,000
1/16	1,500,000	650,000
1/24	1,231,000	838,000
Two veneers, cross-laminated		
1/10	1,928,000	--
1/16	1,960,000	--
1/24	1,543,000	--

From column 2 it is seen that, except for panels with 1/10-inch veneer in two-ply construction, MOE parallel to the grain increased with increasing veneer thickness. For one-ply faces, MOE across the face grain decreased as veneer thickness increased (col. 3).

Face and core constructions interacted to affect MOE:

Face and core constructions	Stressed parallel	Stressed perpendicular
	---psi---	
Single veneer		
Random	1,731,000	314,000
Oriented	1,393,000	735,000
Three-layer	1,462,000	781,000
Two veneers, cross-laminated		
Random	1,737,000	
Oriented	1,906,000	
Three-layer	1,788,000	

When stressed parallel to the grain of outermost veneers, panels with two veneers on each face and with oriented cores had highest MOE (1,906,000 psi); panels with two-ply faces and random or three-layer cores did not differ much in MOE. Panels with single veneers on each face had greatest MOE if fabricated with random cores (1,731,000 psi).

As with MOR, MOE across the grain of panels with single face veneers was lowest for random core construction.

Dimensional Stability

Table 2 summarizes average water absorption, linear expansion, and thickness swelling for each combination of face and core construction.

Water absorption.—Absorption ranged from 74 to 96 percent for the 5-hour boil and from 84 to 105 percent for the 24-hour VPS. It was consistently greater in VPS than in the 5-hour boil. Panels with two veneers on each face, and resultant thin cores, absorbed less water than those with a single veneer on each face.

Face construction and veneer thickness interacted:

Face construction and veneer thickness, inch	Water absorption	
	VPS	5-hour boil
	---%---	
Single veneer		
1/10	105	94
1/16	100	94
1/24	99	95
Two veneers, cross-laminated		
1/10	88	78
1/16	90	82
1/24	95	84

In the VPS test, water absorption increased as veneer thickness decreased in two-ply faces; in single-ply faces, however, absorption increased directly with veneer thickness.

In the 5-hour boil test, veneer thickness was not related to absorption in panels with one-ply faces. In panels with two face plies, absorption increased slightly as veneer thickness decreased.

Thickness swelling.—Average thickness swell ranged from 22 to 57 percent in the 5-hour boil and from 20 to 32 percent in VPS. The 5-hour boil consistently caused more swelling than did the VPS test. In both tests, face construction and veneer thickness interacted:

Face construction and veneer thickness, inch	Thickness swelling	
	VPS	5-hour boil
	---%---	
Single veneer		
1/10	30.0	56.4
1/16	24.9	47.2
1/24	24.8	49.2
Two veneers, cross-laminated		
1/10	20.7	25.3
1/16	24.5	31.9
1/24	24.3	34.5

Table 2 — DIMENSIONAL STABILITY OF PANELS WITH SOUTHERN PINE VENEER FACES AND CORES OF SOUTHERN HARDWOOD FLAKES, AS MEASURED BY VACUUM-PRESSURE-SOAK AND 5-HOUR-BOIL TESTS.

Number and thickness of face plies (in.)	Flake core	Vacuum-pressure-soak: Water absorption	Vacuum-pressure-soak: Thickness swell	Vacuum-pressure-soak: Linear[1] expansion, Parallel	Vacuum-pressure-soak: Linear[1] expansion, Perpendicular	5-hour-boil: Water absorption	5-hour-boil: Thickness swell	5-hour-boil: Linear[1] expansion, Parallel	5-hour-boil: Linear[1] expansion, Perpendicular
		%							
One ply									
1/10	R	105.3	29.7	0.226	1.996	93.7	56.5	0.193	1.619
	O	104.9	31.5	.871	.364	94.3	56.1	1.303	0.781
	L	104.6	28.6	.317	.563	93.9	56.4	.620	1.116
1/16	R	101.2	24.2	.142	.617	95.3	46.5	.191	1.794
	O	101.0	27.9	1.148	.177	95.4	47.2	1.653	.386
	L	96.5	22.5	.555	.561	92.5	47.9	.640	1.956
1/24	R	100.9	20.0	.212	.481	95.8	40.5	.345	.518
	O	97.3	29.9	1.148	.293	94.8	53.9	1.370	.452
	L	98.2	24.6	.540	.673	93.9	53.3	1.013	1.413
Two plies									
1/10	R	91.4	20.2	.577	.709	83.5	30.1	.543	.567
	O	83.5	21.7	.359	.627	73.6	22.8	.652	.696
	L	90.8	20.1	.463	.668	77.6	23.0	.501	.706
1/16	R	90.8	23.2	.320	.462	86.2	30.2	.282	.458
	O	86.0	25.9	.201	.710	80.2	33.2	.175	1.063
	L	94.0	24.4	.433	.509	78.9	32.3	.624	.505
1/24	R	94.9	24.1	.369	.254	87.6	32.0	.286	.424
	O	91.3	24.9	.211	1.112	83.0	36.9	.137	1.707
	L	96.9	23.9	.800	.542	81.3	34.7	.807	.692

[1]As evaluated parallel and perpendicular to the grain of outermost face veneers.

In VPS tests, 1/10-inch veneer and two-ply faces resulted in least thickness swelling (20.7%); 1/10-inch veneer applied singly to panel faces had most swelling (30.0%). With 1/16- and 1/24-inch face veneers, little difference was noted between one- and two-ply construction.

In the 5-hour boil, panels with one-ply faces consistently swelled more than panels with two-ply faces; this was true for all veneer thicknesses. As in the VPS tests, 1/10-inch veneer and two-ply faces resulted in least thickness swelling (25.3%); 1/10-inch veneer applied singly to panel faces had most swelling (56.4%).

In panels with one-ply faces, random core orientation yielded least thickness swelling. With two-ply faces, swelling did not vary significantly with core construction:

Face and core construction	Thickness swelling (%): VPS	Thickness swelling (%): 5-hr. boil
Single veneer		
Random	24.6	47.8
Oriented	29.7	52.4
Three-layer	25.3	52.5
Two veneers, cross-laminated		
Random	22.5	30.8
Oriented	24.1	30.6
Three-layer	22.8	30.6

Panels with single-ply faces had best integrity if constructed with random cores. After the 5-hour boil

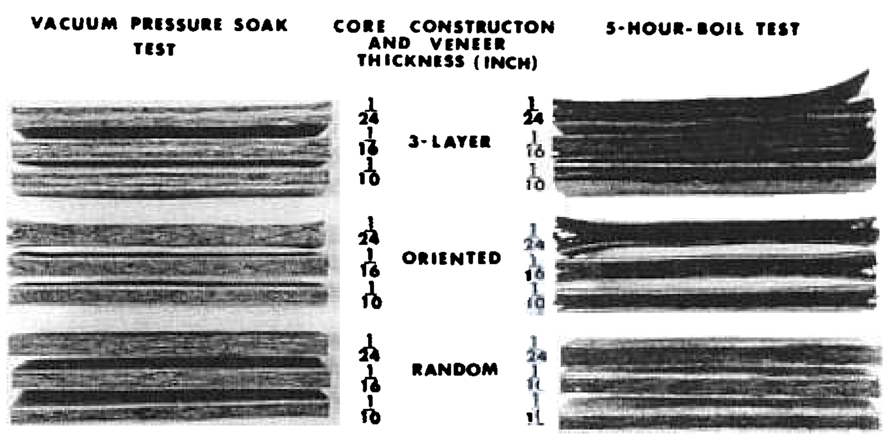

Figure 2. — Delamination of composite panels with single veneers on each face after VPS test (left) and 5-hour boil (right).

severe delamination was observed in panels with three-layer and oriented cores; delamination was less severe in such panels when subjected to the VPS test (Fig. 2). The superior stability of random cores is further evident from Figure 3. Three-layer and oriented cores exhibited delamination and deformation.

Linear expansion.—Ranges of average linear expansion (parallel to grain of outermost face veneer) were 0.137 to 1.653 percent in the 5-hour boil and 0.142 to 1.149 percent in VPS.

As did thickness swelling, linear stability differed significantly with flake-core arrangement:

Face and core construction	Along-the-grain expansion (%) VPS	Along-the-grain expansion (%) 5-hr. boil
Single veneer		
Random	0.193	
Oriented	1.056	
Three-layer	.476	
Two veneers, cross-laminated		
Random	.422	.370
Oriented	.257	.321
Three-layer	.565	.644

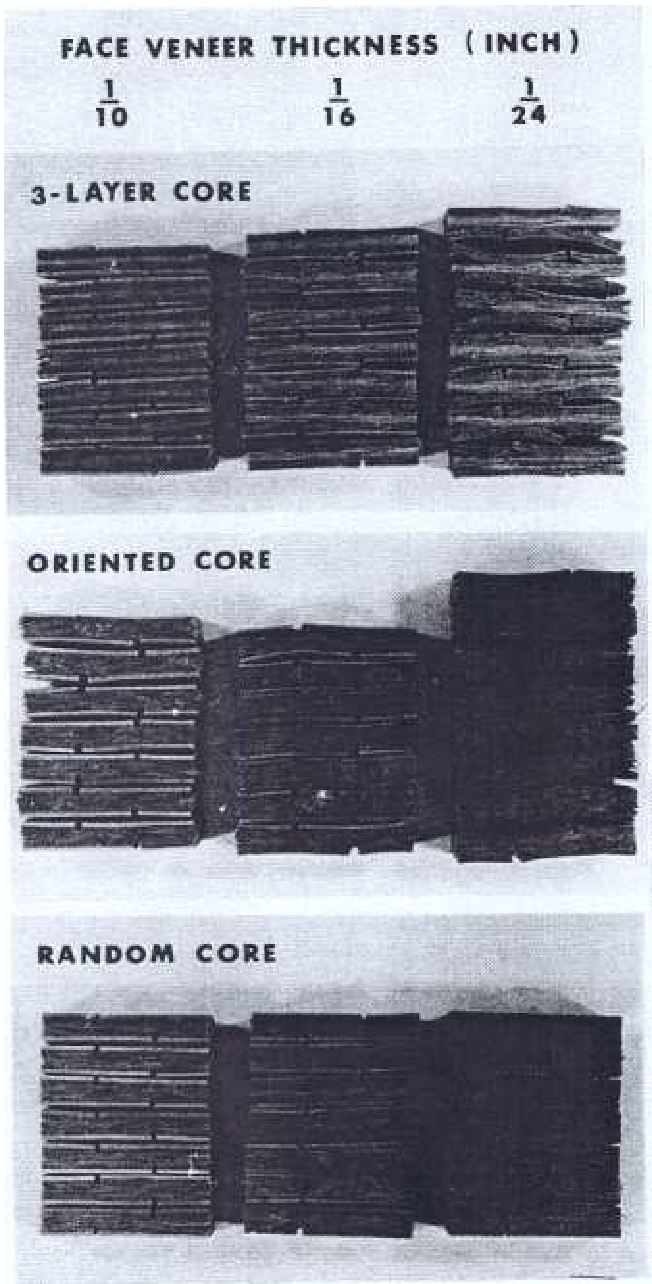

Figure 3. — Deformations and delaminations in composite panels with single veneers on each face, after VPS tests. Specimens were prepared as if for plywood shear tests.

Panels with one-ply faces had most linear stability if provided with random cores; stability was poorest with oriented cores. Panels with two-ply faces were most stable if constructed with oriented cores; three-layer cores yielded least linear stability.

Expansion across the grain of the outermost veneer differed substantially from that measured along the grain (Table 2). Averages for the three types of core construction were:

Face and core construction	Across-the-grain expansion (%) VPS	Across-the-grain expansion (%) 5-hr. boil
Single veneer		
Random	1.032	
Oriented	.278	
Three-layer	.599	
Two veneers, cross-laminated		
Random	.475	.483
Oriented	.816	1.155
Three-layer	.573	.634

With one-ply faces, stability across the grain was best when cores were oriented. With two-ply faces, random cores yielded the most stability.

Face construction and veneer thickness interacted to affect linear expansion across the grain. Except with 1/10-inch veneer in two-ply faces, linear expansion increased as veneer thickness decreased:

Face construction and veneer thickness (in.)	Across-the-grain expansion (%) VPS	Across-the-grain expansion (%) 5-hr. boil
Single veneer		
1/10	0.534	0.705
1/16	.614	.828
1/24	.634	.909
Two veneers, cross-laminated		
1/10	.466	.565
1/16	.318	.360
1/24	.460	.410

Table 3. — COMBINATIONS OF FACE AND CORE CONSTRUCTIONS YIELDING PANELS WITH BEST PROPERTIES.

Property and measurement direction in relation to grain of outer face ply	Single veneer on each face	Two veneers cross-laminated on each face
MOR (psi)		
With grain	Random (9,153)	Oriented (13,161)
Across grain	Oriented (5,277)	
MOE (1,000 psi)		
With grain	Random (1,731)	Oriented (1,906)
Across grain	Three-layer (781)	
Thickness swelling, VPS (%)	Random (24.6)	Random (22.5)
Linear expansion, VPS (%)		
With grain	Random (0.193)	Oriented (0.257)
Across grain	Oriented (0.278)	Random (0.475

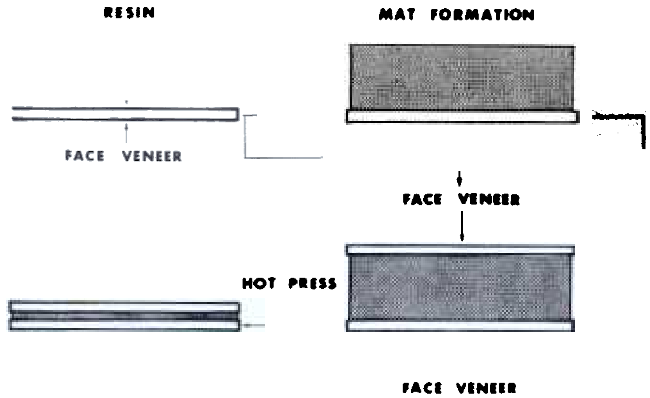

Figure 4. — Sequence of glue spreading, mat formation, and one-step hot-pressing in manufacture of a composite panel with single-veneer faces and flake core.

Discussion

The purpose of this research was to determine optimum configuration of an exterior structural panel with faces of southern pine veneer and core of mixed southern hardwood flakes. Table 3 summarizes the results in terms of the construction giving best performance in each property tested.

Two veneers, cross-laminated on each face over a core of oriented flakes, yielded strongest panels. Nevertheless, panels with single-ply faces over random cores appeared more than adequate for most structural applications; MOR was 9,153 psi when averaged over the three veneer thicknesses tested, and MOE was 1,731,000 psi. Economy in use of veneer also favors single-ply faces.

For panels with single-ply faces, a random core is preferable to oriented or three-layer cores in most properties, even though such construction is less stable across the grain direction of the face veneer. Both strength and dimensional stability across the grain can be modified by altering thickness of face veneers; i.e., strength decreased and linear stability increased as veneer thickness decreased. From present data, the 1/16-inch thickness may be a good compromise for commercial applications.

The simplicity of single-ply faces and ease of forming random-flake cores makes such construction the best candidate for a one-step hot press operation in existing panel plants. Figure 4 schematizes the proposed manufacturing technique.

Literature Cited

1. Batey, T. E., Jr., P. W. Post, D. Matteson, and G. A. Ziegler. 1975. Flexural design procedure for the composite panel. Forest Prod. J. 25(9):49-55.
2. Biblis, E. J., and Y-M. Chiu. 1972. Preliminary results of promising new structural sandwich wood panels for floors and other applications. Wood and Fiber 4(3):151-157.
3. Countryman, D. 1975. Research program to develop performance specifications for the veneer-particleboard composite panel. Forest Prod. J. 25(9):44-48.
4. McKean, H. B., J. D. Snodgrass, and R. J. Saunders. 1975. Commercial development of composite plywood. Forest Prod. J. 25(9):63-68.